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AUTHOR Smith, Valerie F.; And Others
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ABSTRACT

The use of science fiction can be a valuable tool for constructing a highly mental schema in a learner on which to build new learning, to stimulate creative problem solving, and to generate the flexibility needed for adjusting to a rapidly changing, progressively technological society. By using science fiction in a science class, a science teacher can focus on the science concepts around which the story is built. Identified from the reading, English, and social studies educational research literature are effective strategies for teaching concepts through reading, motivating children to read, examining values and social issues, and methods used specifically for teaching science concepts. Problems inherent in the use of literature in the classroom are examined and recommendations for solutions offered. A science fiction book list for use in the junior and high school classroom is appended. (KR)

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Teaching the Science in Science Fiction

Valerie F. Smith
Department of Curriculum & Instruction
Louisiana State University

Jessica P. Scott
Chairman, Science Department
Jackson High School

Wayne R. Coskrey
Executive Producer
Starry Messenger Productions

A Paper Presented to the 1990 Annual Meeting of the American Association for the Advancement of Science, New Orleans, Louisiana, 15-20 February, 1990

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Teaching the Science in Science Fiction

The use of science fiction can be a valuable tool for constructing a highly networked mental schema in a learner on which to build new learning, to stimulate creative problem solving, and to generate the flexibility needed for adjusting to a rapidly changing, progressively technological society. Reading science fiction provides vicarious experiencing of both the proposed solutions to social and physical problems and the potential consequences of a set of actions taken.

By using science fiction in a science class, a science teacher can focus on the science concepts around which the story is built. Such a focus would help to clarify the concepts for the learner and motivate him. However, many science teachers are unfamiliar with the strategies needed for teaching a work of fiction. Nor do they have a list of books appropriate for use with children and categorized by the concepts contained in the books.

This workshop will address these needs. From the reading, English, and social studies educational research literature, we have identified, and tried, effective strategies for teaching concepts through reading, motivating children to read, and examining values and social issues. Additionally, we have included methods specifically for teaching science concepts. Several of these strategies will be discussed. Also, problems inherent in the use of literature in the classroom will be examined and recommendations for solutions offered. Finally, a book list of appropriate works will be distributed.

Introduction: Goals of Science Education and Scientific Literacy

Lately among science educators there has been much debate over what should be taught in the science classes of future elementary and secondary schools (Yager, 1984a). There is agreement on the need to teach science process skills, science knowledge, and problem solving in ways that will foster scientific and technological literacy (Harms & Yager, 1981; Holden, 1989; Koshland, 1989). (For the defining characteristics of scientific and technological literacy, see Table 1.) But there is still disagreement over the place of values, ethics, and societal issues in the science curriculum. Some science educators feel that academically-oriented science and problem solving should remain the central focus of science education (Good, Herron, Lawson & Renner, 1985). Others, those predominant in what is called the STS movement, call for the inclusion of values, ethics, and societal issues in ways that make science education more relevant for the student (Bybee, 1986; Piel, 1981; Yager, 1983, 1984a & 1985). We side more on the STS side of the debate.

The acronym *STS* stands for "Science-Technology-Society" and represents a movement that has been formalized by the organization of the National Association for Science, Technology and Society. The movement began as a coalition of professional scientific, philosophical, technological, and educational organizations. Sharing a common interest in examining the values, ethics, and societal issues of science and technology, STS adherents profess an aim to educate the public towards scientific and technological literacy.

We have listened to talks by science educators such as Hurd, Tamir, and Yager at the 1988 NASTS conference. These men have written about the need for STS teaching

Table 1

Characteristics of Scientific Literacy as condensed by Yager (1984) in summarizing the position of National Science Teachers Association.

The scientifically/technologically literate person

--uses science concepts, process skills and values in making responsible everyday decisions;

--understands how society influences science and technology as well as how science and technology influence society;

--understands that society controls science and technology through the allocation of resources;

--recognizes the limitations as well as the usefulness of science and technology in advancing human welfare;

--knows the major concepts, hypotheses, and theories of science and is able to use them;

--appreciates science and technology for the intellectual stimulus they provide;

--understands that the generation of scientific knowledge depends upon the inquiry process and upon conceptual theories;

--distinguishes between scientific evidence and personal opinion;

--recognizes the origin of science and understands that scientific knowledge is tentative and subject to change as evidence accumulates;

--understands the applications of technology and the decisions entailed in the use of technology;

--has sufficient knowledge and experience to appreciate the worthiness of research and technological development;

--has a richer and more exciting view of the world as the result of science education; and

--knows reliable sources of scientific and technological information and uses these sources in the process of decision making.

Note: Adapted from The major crisis in science education, by R. Yager, 1984, *School Science and Mathematics*, 84, 189-197.

in science education literature (Bybee, 1986; Bybee & Mau, 1986). Additionally, they have been instrumental in formulating current goals of science education through activities with the National Science Teachers Association, as reported in *What Research*

Says to the Science Teacher, Volume 3 (Harms & Yager, 1981). Kyle's (1984) comparison of the nature of the current goals with those of the 1960's is shown in Table 2. What is new about the current goals is the emphasis on teaching the student to

Table 2

Comparison of the 1960's Goals of Science Education With the Goals of the 1980's and Beyond

During the 1960's	During the 1980's and Beyond
1. The demand was to produce more scientists and engineers to solve perceived problems.	1. The needs are related to current social problems rooted in science and technology, e.g., depletion of energy sources, fear of nuclear energy, genetic engineering.
2. Programs were designed to meet the goals of past times in each of the science disciplines. Acquisition of knowledge was still important.	2. There is an urgent need to recognize current societal problems. The knowledge that should be considered important is that which will be useful and relevant to the solution of social problems.
3. Science was taught as a means of advancing knowledge and explanation. Science education was, therefore, preparing future scientists.	3. Science and technology are considered to be a means for improving society. Science education, therefore, should be preparing the future citizens.
4. Science and science education were oriented to the present and immediate past.	4. Science and science education must be oriented to the future in light of its potential impact in helping to resolve societal problems and concerns.
5. Science education concentrated upon the development of cognitive skills.	5. Science education must focus not only on cognitive skills, but upon affective, ethical, and aesthetic understandings as well.
6. Science was viewed as value-free, empirical science.	6. Today's science is more accurately portrayed as value-laden science in which there are moral and ethical dimensions.
7. Science demanded linear thinking and emphasized inquiry skills.	7. Science must be concerned with systemic thinking and emphasize decision-making skills.
8. The goals of science teaching were internal to the various disciplines of science.	8. The goals of science teaching are derived from the interaction of science, technology, and society.

Note: Copied from "Curriculum development projects of the 1960's" by W. C. Kyle, Jr., *Research Within Reach: Science Education* (p. 14) edited by D. Holdzkom and P. Lutz , 1984, Washington, D.C.: National Science Teachers Association.

make everyday decisions based on science knowledge and using scientific thinking skills. This emphasis appears to be reasonable and important to us. We expect that such an emphasis will help alleviate the problem of alienation of students from science as decried in the past by Hurd (1983), Linn (1987), Prather (1985) and others.

A quick look at Table 2 will show that not only is there a strong STS focus in the goals, but that the teaching strategies needed to accomplish these goals will be drastically different from the past set of laboratory exercises, paper-and-pencil problems, lectures, question-and-answer sessions, demonstrations, and textbook readings. These goals call for a more personal involvement by the student in science. They also require teaching strategies that foster consideration of the consequences of science and technology, decision-making strategies, problem-solving heuristics, practice in using the science process skills, and integration of other subject area competencies with science skills. Teaching methods required for such a holistic science curriculum include class discussion, decision-making and values clarification, projects, critical analysis of text, and content reading strategies in addition to the currently accepted inquiry-oriented science methods (Bybee, 1986; Harms & Yager, 1981; Mitchener & Anderson, 1989).

Rationale: Using Science Fiction in a Science Classroom

We believe that using science fiction in a science classroom in specific ways will also help develop skills of scientific and technological literacy. Science fiction can be the medium for using the strategies necessary to accomplish the goals of science teaching, especially those with an STS influence.

Table 3

Comments on Science Fiction

"The greatest human significance of science fiction may be as experiments in the future, as explorations of alternative destinies, as attempts to minimize future shock." -- Carl Sagan (1980, p. 7).

"Likewise, science-fictional encounters with alternative cultured futures may play an important role in actualizing fundamental social change." -- Carl Sagan (1980, p. 8).

"Science fiction is international ... we've been shown as just one more evolving species in danger of extinction." -- Jack Williamson (1980, p. 10).

"What science has given us, is the open universe ... All connections are possible. All alternatives thinkable. It is not a comfortably reassuring place. It's a very large house, a very drafty house. But its the house we live in.

"And science fiction seems to be the modern literary art which is capable of living in that huge and drafty house, and feeling at home there, and playing games up and down the stairs, from basement to attic.

"I think that's why kids like SF, and demand to be taught it, to study it, to take it seriously. They feel this potential it has for playing games with and making sense and beauty out of our fearfully enlarged world of knowledge and perception." -- Ursula Le Guin (1980, p. 25).

"We feel that science fiction is a particularly effective vehicle to teach levels of meaning ..." -- Elizabeth Calkins and Barry McGhan (1980, pp. 83-84).

"To understand the problem of the high school reader, look at the opening of Heinlein's *The Puppet Masters*. The young reader is asked to construct a society in which there exists a super-secret spy organization unknown even to the CIA; to place the action far enough into the future so that technology of instantaneous surgery is possible; and to construct, on the basis of part of a sentence '... on the Northside launching platform, high above New Brooklyn and overlooking Manhattan Crater,' a history of the world which has had an atomic disaster severe enough to have created a "Manhattan Crater" but from which the world has recovered to the point of supporting an advanced technology. For the high school student who has little concept of the passage of time... or knowledge of the location of Manhattan, the effectiveness of these clues is lost." -- Elizabeth Calkins and Barry McGhan (1980, pp. 87).

"This is an excellent opportunity to talk about the nature of knowledge, and model building, and Occam's Razor." -- Stanley Schmidt (1980, p. 116).

" ... [I]n my opinion, to be acceptable as good science fiction, such hypothetical principles must be introduced in such a way that they don't contradict any accepted principles in any region of experience where the accepted principles have been directly tested. That is, a science-fictional innovation should satisfy what I might call the 'negative impossibility' criterion: nobody should be able to prove it's impossible at the time of writing. (Since we're learning new things all the time, it would be both unfair and impractical to require that it be demonstrably possible.) Whether or not this criterion is actually met by a particular speculation is not always an easy question. Aserious attempt to answer it may force students (and teachers) to think as they have never thought before about what they mean by "know." -- Stanley Schmidt (1980, p. 111).

Note: All quotations found in *Teaching Science Fiction: Education for Tomorrow*, edited by J. Williamson, 1980, Philadelphia: Owlswick Press.

Why science fiction? Others have eloquently expressed their reasons for using science fiction in science classrooms (Table 3). We summarize these reasons as follows:

1. SF has the potential to motivate students to like science (Brice, 1980; Reynolds, 1977; Sagan, 1980; Texley, 1988; Zander, 1975).

2. SF models the thinking of a scientist involved in scientific problem solving and inquiry (Friedman, 1979; Romey, 1980).

3. SF presents the science world-view (Adair, 1983; Friedman, 1979; Goswami, 1984; Lamb, 1975; McKinley & Doherty, 1979; Reynolds, 1977; Slusser & Rabkin, 1986).

4. SF depicts a scenario in which science concepts and theories derive the action and force the consequences of that action, illustrating how science and technology affect students' lives both personally and socially. (Allen, 1973; Kafka, 1975; Le Guin, 1980; Nicholls, 1979; Reynolds, 1977).

5. SF examines scientific issues from the standpoint of potential solutions or action and possible consequences of actions taken (Friedman, 1979; Williamson, 1980b).

6. SF models possible futures, enabling students to anticipate and adapt to changes, trends, and possibilities of their own future (Asimov, 1980; Boutzev, 1984; Karantsev, 1984; Lamb, 1976; Le Guin, 1980; Pell, 1977; Reynolds, 1977; Sagan, 1980; Wendell, 1980).

7. SF provides a needed link between the sciences and the humanities, broadening the educational scope of both (Friedman, 1979; Greenlaw, 1979; Pincus,

1975; Wilson, 1980; Zander, 1975).

8. SF provides practice for learning the skills of reading expository materials (Calkins & McGhan, 1980; McGhan, 1982; Zander, 1975).

9. SF fosters vivid mental images of phenomena studied in science (Brice, 1980; Elbow & Martinson, 1980).

The purpose of this technical session is to offer specific teaching strategies compatible with science and STS teaching, and to offer a list of selected science fiction works appropriate for use in middle and secondary school science teaching. The list of books (Appendices 1 & 2) contains not a synopsis of the story, but remarks on some science concepts, societal issues, ethical issues, and values covered in each book (Smith, Scott & Moncado, 1988). As with all materials to be used in a classroom, materials should be personally screened by the teacher before classroom use, as local community values are a reality with which science teachers must deal. Personally, we have no objections to discussing sexuality and violence with children, but parents and school boards do have the right to object.

Problems: Some Objections and Counter-Arguments

Besides the issue of suitability of subject matter in adult fiction for use with youth, there are also other objections to using science fiction in science classrooms. Below is a list of seven possible objections (Smith & Edwards, 1988), many of which have been expressed by fellow teachers in informal conversation and alluded to in Williamson's *Teaching Science Fiction: Education for Tomorrow* (1980).

1. Reading science fiction could create misconceptions (Romey, 1980) that will be

hard to overcome (Pines & West, 1986).

2. Reading science fiction takes time away from the actual doing of science.

3. Reading science fiction could foster social attitudes and values (Enqdahl, 1975) inconsistent with one's upbringing.

4. Many stories deal with subject matter that some would call inappropriate for young students.

5. There is some sexual stereotyping in the stories.

6. Assigning the reading of science fiction could cause students to make lower grades in science based on an activity that is not science teaching.

7. Many books of this genre are written at the 11th grade reading level and are abstract (McGhan, 1982), making them too difficult for today's junior and senior high students.

Looking more closely at these objections, let us first consider the danger of generating misconceptions. Science fiction, by its very nature, presents non-science in a way that is highly believable for the duration of the story (Allen, 1973; Sagan, 1980). Schmidt (1980) recommends that the teacher who uses science fiction be up to date in his knowledge of scientific frontiers so that he can instruct students as to which component of the world presented is fictional. Some (Barow & Salesi, 1982; Sherwood, Kinzer, Bransford & Franks, 1987) suggest an inquiry-oriented approach that encourages students to use both library and laboratory research to define the real science concepts and to detect the fictional ones. This approach would require that the science fiction ideas become an integral part of a science lesson, offsetting the

objection that science would not be what is taught. It also demands that any misconceptions gained from the science fiction reading would be recognized as such by the students.

Another approach would be to use the ways the theories in the books govern the outcomes of the stories as examples of how facts are interpreted within theoretical frameworks (Allen, 1973; Calkins & McGhan, 1980). Additionally, the consequences of any story's applied science, as emphasized by Le Guin (1980), could be examined for whether they are consistent with that book's theories. This critical analysis of the text could then be extended to the student's knowledge of his world: What theories govern such-and-such situations (Calkins & McGhan, 1980)? After such a discourse, the fictional science can be separated from the actual science either by the teacher or the student (Calame, 1973; Freedman & Little, 1980; Schmidt, 1980). The key skills in this approach are inquiry and critical analysis, thinking skills necessary for scientific literacy. The key concepts are those that deal with the nature of science. Again, in response to the objection that science fiction takes time away from actual science teaching, we assert that science is taught with lessons involving science fiction (Smith, et al., 1988).

On the problem of the development of new values: yes, this will happen (Calkins & McGhan, 1980). It will happen through the shaping of attitudes. Many protagonists in the hard-core science fiction genre are critically rational, a scientific attitude fostered by science educators. If we are to believe the science education literature on attitudes, then we must conclude that this rationalist attitude is not held by the beginning science student or the public (Lederman, 1986).

Furthermore, these science fiction heros are often concerned with a global

problem and seek solutions that exhibit a loyalty to mankind rather than a nationality or ethic group. Often they seek answers to moral problems with their reasoning rather than from an imposed morality (Williamson, 1980a; Phillips, 1984). These themes are reflected in Kurtz' (1983) discussion of secular humanism, a controversial set of values that, in our opinion, mirror many goals of modern science education as presented by Project Synthesis (Harms & Yager, 1981).

How do the values of the protagonist affect the reader? Some (Calkins & McGhan, 1980; Enqdahl, 1975; Fisher, 1980; Schmidt, 1979; Williamson, 1980a) feel that vicariously experiencing the problem, the problem resolution, and the positive consequences of resolutions will cause the reader to identify with the values and attitudes of the story character. Since these values and attitudes are compatible with the goals of science education expressed by Project Synthesis (Harms & Yager, 1981) and are even, in many cases, attitudes cited by Yager (1984b) as those that the science curriculum is designed to foster, then discussing the attitudes, values and behavior of the science fiction characters is desirable. Such discussion offers a chance to expose aspects of the hidden curriculum of science education--the hidden curriculum being the attempt to foster scientific attitudes and values in our students in ways not explicitly obvious to the student (Cummins, Pinar & Good, 1989).

Considering the influence of world views and theories on the importance of facts is an important part of learning the nature of science (Duschl, 1983). In science fiction, such influence can be studied in an artificial world with a concrete relevance to the individual reader (Calkins & McGhan, 1980; Sagan, 1980; Williamson, 1980a). Such relevance is difficult to foster in a novice science student's conceptualization of an

abstract theory. Even when theory is applied to a science laboratory experiment, students barely understand or apply it beyond the narrow sense of the few examples they study. The consequences of the theories, principles, and concepts that drive the story do not only have ramifications for the story. These ramifications become, also, additional examples of the concepts to be added to a student's cognitive repertoire, giving the student a broader base of experience, even if vicarious.

Our discussion so far has dealt with the first three proposed objections to using science fiction in the science classroom. These same points apply to the issue of inappropriate subject matter. To deal with the problem of inappropriate subject matter, we previously suggested that the teacher screen books in advance. We also offer a list of books with which we are familiar. In this list we have commented on books that contain excessively graphic sex and violence passages. We recommend that only excerpts of these particular books be used in the classroom.

On sexual stereotyping of female characters, granted, superficial characterizations exist (Wood, 1980). In fact there is much stereotyping of the values, attitudes, and images of scientists and technologists. Many books we have chosen were written by authors "trained" by John Campbell when they wrote short stories for the magazine he edited, *Astounding Science Fiction* (Asimov, 1972 & 1980). These authors present the critical rationalist stereotype of science itself. Analyzing this condition through class discussion can be a mechanism for further uncovering the hidden curriculum of science teaching and making explicit the scientific world view and attitudes we hope to foster (Williamson, 1980a).

As for grading, there is admittedly the potential to frustrate the students. However,

students consider non-graded assignments to be a waste of their time, so we hesitate not to grade. Grading on a point structure could alleviate some of the anxiety. Using a point structure where only a small percentage of the grade is based on science fiction assignments would allow students to feel that doing the assignments builds up their grade rather than bringing it down. The resultant sense of earning grades will, we feel,, be more effective.

We feel justified in grading science fiction assignments in a science class for three reasons. First, as previously stated, we consider our science fiction lessons to be teaching science. Second, teachers from upper elementary school to college have used science fiction with students and claim that it motivates students to take an interest in science (Kindler, 1982; Williamson, 1980b). Finally, the content reading strategies that we will be presenting in this session can be practiced with science fiction text passages.

The last objection is to the reading level of the adult science fiction genre. Much of the science fiction, unless specifically written for juveniles, is written at an eleventh grade reading level; the writing style is expository and abstract (Enqdalh, 1975; Marks, 1978; McGhan, 1982; Pell, 1977). However, we say that the eleventh-grade reading level and the expository style of science fiction makes these books prime candidates for content reading lessons designed to enhance the students' abilities to read science textbooks.

How do we accomplish the teaching of scientific values, concepts and reading skills using science fiction? We turn our discussion now to a set of strategies useful in the classroom. Some educators have recommended role-playing science fiction stories

(Donlan, 1974; Reynolds, 1977). Some have recommended having students write their own science fiction using science concepts under study (Barra, 1988; Longyear, 1980). Others have suggested using the stories to generate discussion of specific philosophical questions (Meyers, 1980; Phillips, 1984; Reynolds, 1977); and still others to use science fiction to generate interest in science topics and to provide examples for class lecture and discussion (Calame, 1973; Freedman & Little, 1980; Schmidt, 1973). Finally, science educators have encouraged the use of science fiction in inquiry lessons such as laboratory activities and in stages of the Karplus Learning Cycle (LaBianca & Reeves, 1981; Sherwood, et al., 1987; Smith, et al., 1988).

Teaching Strategies: Ways to Use Science Fiction

Now we would like to share with you a set of strategies for which science fiction stories are the central text of the lesson. This set includes a list of questions that can be used to foster an examination of the nature of science. There is also a values clarification strategy called *values continuum* that can be used for teaching various positions on an ethical issue along with tips for fostering the class discussion that is part of the strategy. Finally, a set of content reading strategies for teaching expository text is included. In this set is the *structural component analysis* which can help explicate the storyline of the fiction and the scientific method used in the story. Additionally, a *sequencing activity* and the *content reading simulation* can be used to teach the student text structure and so enhance his reading comprehension.

Examining the Nature of Science. In examining the nature of science, we must first realize that the traditional "Scientific Method" has become a rigid stereotype in classroom practice. It is also more reflective of an empiricist conception of science

rather than more modern philosophical views. Current thought on the nature of science places more emphasis on the relationships of fact and principle to theory (Duschl, 1983). In many science fiction stories, one can map the events of the story to various components of scientific method (Lamb, 1976). Such a map is called a structural component analysis (McGee & Richgels, 1986). Table 4 shows a structural component

Table 4

Structural components as found in *Fuzzy Sapiens*

Problem: Why are the fuzzies dying as a race?

Research: 1. Fuzzies eat land prawns (zatkus).

2. Fuzzies move to a different area where land prawns are plentiful.

3. Nine out of 10 fuzzy births result in still births, premature, non-viable births, or live only one or two hours.

4. Fuzzies love extee three rations.

5. Radiation check of the fuzzy homeland revealed there was not enough background radiation to cause the birth defects.

6. When the supply of extee three is low, the company makes a batch which the fuzzies reject.

7. The two batches of extee three are analyzed and the difference is an organic molecule containing titanium.

8. Land prawns contain a substance called hokfusine which contains titanium.

9. Fuzzies produce a hormone, NFMp, which interferes with normal fetal development.

Hypothesis: Titanium is necessary for normal fetal development.

Experiment: Feed fuzzies foods high in titanium and observe the birthrate. Compare it with the previous birthrate in which the foods had little or no titanium.

Data: Those fuzzies who became pregnant after eating a lot of landprawns and/or extee three had viable fetuses.

Conclusion: Titanium was necessary to neutralize NFMp and result in live births.

Note: Based on *Fuzzy Sapiens* by H. Beam Piper, 1964, New York: Ace Books.

map of the central problem dealt with in *Fuzzy Sapiens* (Piper, 1964). Comparing the maps of several stories will illustrate the flexibility of scientific methodology. Maps from biographies of scientists, history of discoveries, and articles from *Science News* and *Scientific American* can be compared with structural component analysis generated from the fiction. We suggest that you begin with the fiction for fun, then move on to mapping the science. Comparing the two sets helps to point out the science/

Table 5

Examining World Views using Questions with Answers Based on *Starlight* by Hal Clement.

Starlight is the story of Mesklinite sailors working for Earthmen to explore a world similar to their own but 3,000 times more massive than Earth. From a space station, Earthmen provide scientific and technological expertise to the Mesklinites.

World views are philosophical perspectives or paradigms from which one knows his world. Science as a way of knowing is a world view. For example, for some this way of knowing is critical realism; for some it is neo-empiricism; for others, phenomenology. World views apply to different realms of knowledge: physical, as in the physical universe; religious; and social. To understand the story, we must identify the world views and the basic theories depicted in the story. Then we must consider the hypothesis formed within these theories and how these hypothesis are tested and modified in the story. Analyze *Starlight* by answering the questions below.

1. Identify the world views used by the characters in the story upon which the majority of decisions are based.

The Mesklinites and the Earthmen operate mostly from a critical realist point of view. The Mesklinites are pragmatists. The world is viewed from a scientific perspective.

The Mesklinites are traders, with a social structure based on exploration and commercial trade. The leader is the captain of the ship. The chain of command is that of a ship's crew. The Earthmen are all scientists who are members of a spaceship crew. They have social relationships based on rank and job expertise. For both cultures, the social world view is humanistic and pragmatic.

2. Identify the theory behind the science of a particular passage.

The Mesklinites' ship is stuck on a patch of ammonia-water ice. The theories are that phase changes of solutions occur at temperatures and pressures determined by the concentration of the solution and that weather is predicted from barometric pressure and temperature in the manner of chaos theory of thermodynamics.

3. Identify the hypotheses that the individuals formed to deal with their situation.

It will get colder and the fog will clear. The wind will decrease gradually. The storm winds will

(Continued next page)

(Table 5, Continued)

continue for another 45 hours. The ice under the ship will not melt.

4. Tell how the hypotheses was tested and retained or exchanged.

The main hypothesis of interest to the story is that the ice would not melt. It melted. To explain the unexpected results, data on the concentration and composition of the ice solution was reexamined.

5. Will the world view change?

No. However, the Mesklinites began to understand the role of theory on the predictions and facts that the Earthmen had been using to tell them about what to expect. Up to that point, the Earthmen had been the superiors in knowledge. After this false prediction, one of the Mesklinites began to see nature of science as a theoretical understanding expanded through testing of hypothesis (This occurs over the next 30 pages). This understanding further freed the Mesklinites from their dependence on the Earthmen to make all the decisions for them.

6. Did the characters change the theory from which they viewed the situation?

No. However, the emphasis shifted from considering the theory of weather prediction to considering the eutectic principle of phase changes in solutions for explaining what actually happened.

7. What caused them to change the theory or why did they not change the theory?

The theories themselves were still considered sound. The emphasis was just misplaced as to which variables were the most influential in these circumstances.

8. What similar examples from real life can you recall?

Salt on iced-over bridges. Predicting thunderstorms.

Note: Answers are based on *Starlight* (pp. 1-44) by H. Clement, 1971, New York, NY: Del Ray, Ballentine Books.

non-science of the fiction and the lack of rigid methodology in the real science.

One of the goals of science education is to generate in the student an appreciation of the power of science methodology. It is the flexibility of methodology that makes scientific method workable in so many situations. To blend this knowledge with the emerging philosophical method of science, we suggest examining the world views of various stories. Questions for considering the influence of world views are shown applied to Hal Clement's *Star Light* (1971) in Table 5.

Examining Issues and Values. Often getting students to begin a discussion on controversial issues is difficult. Insuring that all students take part requires teacher

Table 6

A Values Continuum for *Star Trek: The Next Generation*: "Up the Long Ladder."

While on a planet populated by clones of the original settlers, Riker and Pulaski are asked to donate tissue for propagating a series of clones to replace a line that is becoming defective. When the Enterprise crewmembers refuse, they are rendered unconscious and have tissue stolen from their bodies. When Riker and Pulaski discover the tissue theft, they return to the planet and destroy the almost fully-developed clones of themselves. The colonists claimed that without the new line of cells, their colony would die out in a few generations.

Did Pulaski and Riker have the right to destroy the clones?

Note: The Values Continuum is adapted from *Teaching Science Through Discovery*, 6th ed., by A. Carin and R. Sund, 1989, Columbus Ohio: Merrill Publishing Company. The film is "Up the Long Ladder." *Star Trek: The Next Generation* by M. Snodgrass (author), 1989.

orchestration. The values continuum as discussed in Carin and Sund (1989) is an effective tool. The teacher presents the class with a diagram of a values continuum such as the one in Table 6, where it has been applied to "Up the Long Ladder," an episode of *Star Trek: The Next Generation* (Snodgrass, 1989). Students are asked to take a stand somewhere on the continuum, by first writing their position on their own

paper. This step forces each student to respond. They then mark the class diagram with their position by writing their names along the values continuum. This activity is followed by class discussion.

If the values continuum does not generate spontaneous class discussion, or if only a few students are participating, additional strategies should be used. Carin and Sund (1989) suggest having students discuss their position with the people next to them on the continuum, or with persons at the other extreme. We would suggest using both combinations, allowing students to marshal their reasons in discussion with people next to them on the continuum. Then, in small groups, use these reasons as a basis for discussion.

Another discussion-generating strategy is called processing activity. Once the material to be discussed has been presented, and the initial questions posed, students pair up. Each student is then to speak to his partner for a full minute about the questions. Time is called, and the other partner speaks for one minute. The pairs then move into larger groups where a group discussion begins by inviting the pairs to share their findings with the group.

Another technique is to have each student write down three to five one-sentence responses to the questions posed. Whole class discussion begins with asking students to share one of their responses with the class. This can continue round-robin until members of the class begin responding to the statements of their classmates. Later, the open discussion can be brought back on track by asking for additional response statements.

Content Reading Skill: Sequencing. Pre-college students often have difficulty sequencing events. Anyone who has tried to get high school students to describe mitosis has had first-hand evidence of this difficulty. To overcome the problem, have the students practice listing the actions of a story in chronological order. An example of

Table 7

A Sequencing Exercise based on *Door into Summer*

___Danny invents many machines in secret and then goes to take the cold sleep he contracted for.

___Danny is bilked out of his company, gets drunk, and decides to go into cold sleep so that he will have a better future. He pays for the cold sleep and then sobers up.

___Danny wakes up in the future a rich man, and marries the girl he convinced to take the cold sleep (after she grows up), and who is awakened at the same time he is.

___Danny wakes up 30 years in the future and discovers that he has invented machines he does not remember inventing.

___Danny accidently discovers that there is such a thing as a time machine. He tricks the inventor into sending him back into the past to about a month before he took cold sleep.

____Danny decides to confront his partner and girlfriend who cheated him. To get rid of him, they drug him and put him into cold sleep.

Note: Based on *The Door into Summer* by R. Heinlein, 1957, New York: Signet.

this strategy can be found in Table 7, where it applied to Heinlein's *A Door Into Summer* (1957). Stories especially good for advanced practice are those in which the action switches to flashbacks, simultaneous activity, or precognitions. Note that mentally ordering events depicted in a text is a reading skill that requires visualizing the action of the story and much practice. For some students you might have to point out the phrases that designate time relationships. This will be a useful skill to develop in students since science word problems, laboratory instructions, and event descriptions

are difficult for reluctant readers who have trouble keeping track of the sequence of events (Calkins & McGhan, 1980; Howland, Jarvie & Smith, 1943).

Table 8

Content Reading Simulation presented in three phases.

The passage used is the short story "The Deep" by Isaac Asimov. "The Deep" is about telepathic creatures from a planet orbiting a dying sun. They devise a way to move their population to another planet, the Earth. Roi is sent to set up the receiving station that will guide them to their new home. Roi uses the minds of Earth's people to make his decisions about where to set up the receiving station and to gain information about Earth.

From this story is taken the following statements to be used to help students learn to read for cause and effect.

Phase I. Decide if the first word or phrase in a set stands for a possible cause of the second word or phrase in the set. Mark each cause/effect set as C/E. The numbers in parenthesis are the page and paragraph numbers on which each set is based. Be ready to defend your answer.

___1. planets die/sun explodes (102:1)

___2. sun explodes/planets die (102:1)

___3. oceans lock in ice/intelligent life survives (102:1)

___4. cooling sun/cooling planet (102:1-4)

___5. offspring/fertilized egg (103:9)

___6. mental problem/mother's interest in offspring (104:1-6)

___7. changing baby/baby smiles (108:7)

___8. alien stimulates mind/baby cries (116:11-13 & 121:7-8)

___9. woman speaks to baby/woman feels pain (116:1,4 & 120:6,8)

___10. alien stimulates mind/woman feels pain (116:1,6 & 120:6,8)

Phase II. Check each statement that is reasonable based on the world of the story.

___1. Roi went to Earth to prepare a receiving station for his people.

___2. The aliens, Roi's people, must move to a new world.

___3. The alien world has no atmosphere.

___4. Colic made the baby cry.

___5. The aliens are bothered by emotion.

(Continued next page)

(Table 8, Continued)

___6. The alien Roi controlled the human minds from the box.

Phase III. Answer the questions below. Be sure to give evidence for your answers.

1. Why did Roi's people need to find a new home?

2. For what purpose was Roi sent to Earth?

3. What was the baby's reaction to Roi and why?

4. Wenda became Roi's friend without telling him who she really was. What would have happened if she had been honest with Roi about her affections?

5. What made the aliens decide to settle within the Earth?

6. Why did the aliens decide not to make contact with the Earthlings beyond Roi's first visit?

Note: Content reading simulations are adapted from "Questioning is Not the Answer" by H. Herber and J. Nelson. in E. Dishner, et al. (Eds.) *Reading in the Content Area, 2nd ed.*, 1986, Dubuque, Iowa: Kendall/Hunt. The page numbers listed are to the version found in "The Deep, by I. Asimov, *The Martian Way...and Other Stories*, 1955, New York, NY: Dell Ray, Ballentine Books.

Content Reading Skill: Reading for Cause and Effect. Another content reading strategy that we recommend is the use of the content reading simulation (Herber & Nelson, 1986). This strategy is designed to teach the reluctant reader how to identify the cause-effect relationships of expository material. It can be modified to work with descriptions, theory-fact-principle relationships, or other categories of expository text. This strategy is a three-step process that, over several weeks of lessons, teaches students to recognize independently the relationships of information in expository text. We have used one passage to illustrate the various stages of the cause-effect lessons. The example is shown in Table 8 as applied to Asimov's "The Deep" (1955). Normally each different lesson would be based on a different text passage.

Content Reading Skill: Understanding the Story. To most effectively use science fiction in the ways we have mentioned requires that the student first understands the

Table 9

Structural Components of a Story

The Parts of a Story

The Hook: The opening that grabs the reader's attention.

The Backfill: Information that explains why the character is in the situation described in the hook.

The Buildup: The body of the story. Should be a series of problem and problem resolutions, but each one less important than the central problem of the story.

The Ending: Resolution of the central problem of the story.

Putting the Story Together

The Plot: The main character has a major problem to resolve. The problem lands him in trouble. He must solve it through his own efforts.

The Timing: Important for keeping the reader interested. "...[G]et the character to the tree fast, have him struggle among the branches, then, when you have him down from the tree, end the story. (p. 78)"

Characterization: Qualities that the characters possess: includes attitudes and values.

Change: The character of the hero changes due to his efforts to solve his problems.

Believability: The reader must be prepared to accept happenings as believable in the context of the story.

Feelings: The emotions of the author for the story will show through, a factor in making the story interesting.

Note: Adapted from "Science Fiction in the Primary School" by B. Longyear in *Teaching Science Fiction: Education for Tomorrow* (pp. 76-79) edited by J. Williamson, 1980, Philadelphia: Owlswick Press.

story that he reads. The teacher must take a little time to teach the story. One way to teach the story is to have the student identify the major literary elements of the story. Longyear (1980) offers a list of elements with the basic scheme that most science fiction stories follow. He does this in a lecture designed to teach students how to write their science fiction short stories. However, we feel that, just as English teachers do in literature lessons, going over the components of the story with the students helps them better understand the reading. Longyear's structural components are presented in

Table 9 and can be the basis of a storyline structural component analysis to supplement the other maps mentioned above.

Summary: Using the Strategies In a Science Fiction Unit

When you first give the reading assignment, talk about some of the more difficult vocabulary words. Identify for the student some aspects of the plot, character, and setting. Gauge the interest level of the students and tell them tidbits of the story to motivate them to read it. This set of pre-reading activities is then followed by a guided reading assignment, such as mapping the structural components of the story as presented in Table 4. After reading, discuss the examples that the students chose to depict the story line elements. Have the students sequence a set of story actions, as in Table 7. Use the other strategies mentioned in this paper to draw out the teachable moments fostered by the science fiction story. The technique of using pre-reading, guided reading and post reading activities is one recommended by content reading specialists for teaching students to read expository text (Dishner, Bean, Readance, & Moore., 1986).

Remember, many students have trouble reading expository materials (Dishner, et al., 1986; Howland, et al., 1943; Smith, 1989). The content reading strategies that we have discussed were designed to teach the student to read to learn. Also, to deal effectively with the societal issues, values and world views of science, and concepts that can be found in science fiction stories (Williamson, 1980b), the teacher must first determine that the story was indeed read and understood by the student (Calkins & McGhan, 1980). The strategies for dealing with the issues, values, and concepts can then be introduced with a short synopsis of the storyline and the text passage chosen

for the lesson.

In conclusion, science fiction used in specific ways to teach concepts, values, attitudes and reading skills is a rich resource for teaching science. The highly motivational quality of science fiction provides an opportunity for you and your students to get involved in discussing, speculating, and, not incidentally, learning.

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Appendix I

The following booklist was originally presented by V. Smith, J. Scott, and G. Moncada at the 4th Annual Technological Literacy Conference in Washington, D.C., February 5-7, 1988, as part of a paper entitled "Teaching Science with Science Fiction."

Science Fiction Book List for Use in the Junior and High School Classroom

This list is composed of favorites read by at least one of us, often all of us. As high school teachers we have screened these books for passages inappropriate for use with younger children. Many books we would highly recommend as favorite readings are inappropriate for children either because the reading level is too difficult, the story line too abstract, or the sex, violence and/or social issues handled in the book are not considered appropriate for teacher recommendation.

Many excellent books of the genre are not included in this list simply because none of the three of us have read them personally to date. Another reason for exclusion is that many books of the genre are not included because their teaching value applies mainly to a social studies class. If the book does not bring to mind one or more lessons to be taught in a science class, especially one based in the readings of a few short pages, then it was not included in this list. And finally, alas, some works were read so long ago that although the story remains with one of us in memory, the title and author escapes us. Consequently, this list by no means exhausts the possibilities for classroom use. We could not resist the temptation to share some of our favorite adventure stories with you, however, since we are truly fans of the genre. Again, these are stories that we recommend to junior and high school students. We feel that the essence of these adventures is such as will inspire the young reader to consider a scientific or technological career out of the sheer excitement of sharing in the "story of the idea", as some have termed science fiction to be.

Some of the books recommended for upper high school have been read by 8th and 9th graders with great enjoyment. Some that are recommended for junior high are excellent for reluctant readers of the 12th grade. As graduate students, admittedly sci-fi buffs, we have read these as adults and thoroughly enjoyed them all!

Anderson, Poul

FireTime. Environmental adaptation; binary stars; sidereal year and seasons. Possibly better if used in excerpts. Story of social conflict. High school.

Tau Zero. Advanced high school. This novel concerns a crew of star travellers whose space drive has been damaged. This forces the crew to go ever close to the speed of light. All of the consequences of relativity are realistically depicted, and eventually this leads to the ship approaching the end of our universe. Much information on stellar evolution and the cyclic "big bang" theory of cosmology is provided.

We Claim These Stars. High school. Part of a series pitting stellar empires against each other. This novel contains vivid depictions of Jupiter's environment and also contains information about stellar evolution and galactic nebulae. There is lots of exciting action that appeals to the younger reader.

Asimov, Isaac.

A Whiff of Death. Chemistry; scientific method; what it is like to be a scientist. A murder mystery.

Caves of Steel, The. Artificial intelligence, robots, societal adjustment (pp. 5-8, & 12-13). A murder mystery in which a robot is the cop's partner.

End of Eternity. Implications of time travel to the past, other possible worlds. High school due to abstract ideas.

Foundation Trilogy and *End of Eternity,* The. This series gives one a sense of history and a feel for sociology, economics, politics, as well as a feel for living in a technological society. Especially in *Foundation's Edge,* the role of data bases as information sources is illustrated. The power of knowledge, of memes is felt in this example of "future history." High school.

"The Psychohistorians," *Foundation* (p. 1-37). Implications of the power and scope of a mature science, in this case–psychology.

Martian Way, The. Several stories that all depict some aspect of the nature of science and technology in problem solving. In "The Martian Way" the reader experiences life as a spaceship crewmember, citizen of a colony on another planet, and worker in space. Gravity, ice in space, propulsion, space suits and space travel are some of the concepts covered in this short story. In "Youth" is a story of irony that junior high students will enjoy. Caring for pets is one theme. "Sucker Bait" is useful in teaching the scientific method, environmental ecology, and chemical properties. Junior high and up.

Auel, Jean

Clan of the Cave Bear. High school due to length and adult themes and the role of sex in the culture. Prehistory; anthropology; inventions of the basic tools and practices that preceded civilization.

Valley of the Horses. High school due to length and sexual acts explicitly described. Excerpts could be more appropriate. Fine description of the making of an arrowhead and gives meaning to the words fracture, cleavage and other physical properties as applied to rocks (pp. 125-131).

Bova, Ben

Millennium. Advanced high school. This novel realistically depicts lunar colonies and the consequences of low gravity on the human body in addition to being a commentary on the future of space-based anti-ballistic missile defenses.

Out of the Sun. Advanced high school. Near-future space combat is realistically portrayed. There is also a thorough discussion of the practicality of laser energy weapons.

Busby, F. M.

Rebel Dynasty. Advanced high school. This collection of novels shows the impact of time dilation (caused by near speed of light travel), on both the personal relationships of space travellers and on the ability of governments to control interstellar nations.

Calden, Martin

Cyborg. Middle school. Depicts the marriage of man and machine along with the psychological implications of major limb loss.

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Cherryh, C. J.

Pride of Chanur. Advanced high school. This book is the first of a series that is very strong in its depiction of the problems different alien races mighthave communicating.

Clarke, Arthur C.

2001: A Space Odyssey. A classic for artificial intelligence and working in space. Probably at a high school reading level.

2010: Odyssey Two. Sequel to "*2001*". Answers many questions left over from the first book. Scientific method.

Islands in The Sky. Middle school. Very realistic and practical depiction of life in orbit in the near future. Also shown are the effects of low and zero gravity on medicine, agriculture, and engineering.

Rendezvous with Rama. Newton's Three Laws, working in space. Probably high school reading level.

Songs of Distant Earth. Middle school. Implications of slower than light star travel, involving both awake and frozen crew members. The novel also has an intriguing depiction of aquaculture, a fairly regular theme of Clarke's stories. Culture clash; evolution of cultures; space travel of extended time; suspended animation or cryogenic sleep; time; distance.

Clement, Hal

Ice World. Middle school. An alien view of the Earth provides the reader with a whole new perspective on his own planet.

Mission of Gravity. High school due to reading level. Fine examples of biological adaptation to environmental conditions; gravity; psychological perception; communication across cultures; problem-solving. Excellent depiction of the effects of high gravity on the body and on engineering principles.

Needle. Middle school. Excellent portrayal of commensalism as an alien police officer enters the body of a young Earth boy in order to search for a criminal of his own species. The sequel, *Eye of the Needle* was written some 20 years later and provides even more information about commensalism and the problems of communication between alien species.

Starlight. Sequel to Mission of Gravity. Many of the same themes.

Correy, Lee

Shuttle Down. Middle school. A very realistic portrayal of a space shuttle emergency. Also included is excellent information about Easter Island and its culture.

Forward, Robert.

Dragon's Egg. High school due to reading level, junior high if used as excerpts. This book is a sequence of stories that can be used individually in a classroom for teaching number sense (pp. 45-56 & 77-81); evolution (pp. 45-56); life cycles (life functions (mobility, adaptation, nutrition, reproduction among unicellular organisms); domestication of plants (pp. 45-56, 58-63, & 69-92); neutron stars (pp. 1-9); problem solving (pp. 36-41); scientists at work (pp. 9-44); 5 senses as energy receptors (pp. 112-147); gravity; magnetism (pp. 38-41); optics with mirrors (pp. 154-168) and time (pp. 276-280, 260-263 & the entire book). This book is wonderful in its creation of another world.

Foster, Alan Dean

Ice Flegger. Middle school. Survival on a cold weather planet. The book deals with communication with an alien race and also has very creative, but realistic, depictions of possible cold-climate biology.

Gerrold, David

When Harlie Was One. High school. Implications of artificial intelligenceand on the concept of what makes a real person.

Haldeman, Joe

The Forever War. Advanced high school. This Hugo award-winning novel includes (and relies on) the implications of relativistic time dilation. Also of interest is a description of the properties of liquid helium. Warning: Strong sexual content and violence realistically depicted.

Heinlein, Robert.

Farmer in the Sky. Overpopulation, colonization, farming technology, gravity, space travel (pp. 38-46), role of a passenger in a spaceship (pp. 39-82). Large numbers, the vacuum of space, punctured spacecraft, chemicals, chemical and physical properties are all woven into the story within these first set of pages!

Have Spacesuit Will Travel. Spacesuits, space travel. Again, the heroine is a junior high student. Junior high and up.

Podkayne of Mars. Junior high girl solves a colonial problem through her initiative and friendship with Martians. Great adventure. Junior high and up.

Red Planet, The. Housing on an inhospitable planet (pp. 14-15); pressurelocks (p. 149); communication with aliens (pp. 29-40); canals of Mars as waterways (pp. 144-146).

Time For The Stars. Middle school. Junior high and up; effects of Einsteinian time dilation, the classic twin paradox, and the life problems twins have growing up.

Herbert, Frank

Dosadi Experiment, The. High school. Another complex world is created. This book is for a mature reader.

Dune. High school. This book is complex in its adult themes of political, theological and technological issues. Its creation of a world is so real that it is a classic of its type. Ecology; genetic engineering; body language; power struggles; water conservation; environmental engineering; communication. It is difficult to say what excerpts would work out of context with this one.

Whipping Star. High school. This book is offered as an example of the adventure of Herbert's novellas. Read this and others for fun.

White Plague, The. High school. Genetic engineering and germ warfare. For the mature reader due to adult themes.

Hogan, James P.

Code of the Lifemaker. High school due to reading level. Biological adaptation and life functions in analogy since these are applied to robots (pp. 125-136).

Gentle Giants of Ganymede. High school due to length and reading level. Cooperative problem solving between alien societies.

Giant's Star. Third in the sequence of the "Giant" books. Provide this for readers that enjoyed the other two and wish to complete the story.

Inherit the Stars. Evolution; alien biology; taxonomy; scientific method; spacesuits and working on the moon. High school due to length and reading level. Second in the "Giant" series.

Hoyle, Fred and Hoyle, Geoffrey

Fifth Planet. High school due to reading level. Scientific expedition to another planet bring back an alien embodied in an earthling's mind. Interaction of scientist as depicted by the astronomer Fred Hoyle is interesting.

Into Deepest Space. High school due to reading level. Newton's Laws andspace travel superbly illustrated, including the tedium of long voyages.

Hoyle, Fred

Black Cloud, The. High school due to reading level. Scientists as workers and people; communication across cultures; language decoding; energy absorption by dark bodies; scientific method. It takes some physics to understand this book, but for the interested student it is fascinating.

Hoyle, Fred and Elliot, John

A for Andromeda. High school due to reading level. Scientists and problem solving; aliens and communication.

Ing, Dean

Pulling Through. Advanced high school. Frighteningly realistic description of a nuclear attack, showing survival techniques and the consequences of nuclear warfare.

L'Engle, Madeleine

A Wind in the Door. Junior high and up. This is part of a series all of which are equally good. *A Wrinkle in Time* won the Newberry award. The lessons of these books are mostly that it is OK to be intelligent, to like science, and to be different from the other children. Also, the idea of networking ideas to solve problems in a way akin to the ideas of memes and the respect for the methods of science to solve problems make these works of fantasy wonderful reading. There are usually some sciences term central to the story that the reader must concretize to understand the story.

Lieber, Fritz

A Spectre Is Haunting Texas. Advanced high school. This novel shows the effects of normal Earth gravity on a person raised in zero gee. It also has an excellent description of the exoskeleton necessary for this person to survive on Earth.

Llewellyn, Edward

Salvage and Destroy. Artificial intelligence; problem solving; communication across alien cultures; biological adaptation; space travel. Good adventure for high school students. Strong male and female characters. Some allusions to sex, but no descriptions of the actual act in progress.

McCaffrey, Ann

Ship Who Sang, The. High school. This book proposes that the incurably crippled might one day have useful lives as the brains of starships, unbound by their frail human shells.

McCollum, Michael.

Life Probe. High school due to reading level. Artificial intelligence (pp. 7-11 and rest of book); scientists' reaction to UFO encounter--scientist at work; scientific teamwork; data bases; crew of spacecraft, jobs in space (pp. 11-19); scientific method.

Michener, James

Space. History of rocketry (pp. 66-94); the universe (pp. 350-354); astronomical observations (pp. 60-65 & 53-54); preparation of astronauts, preparations for flight, and spaceflight (pp. 496-520); flight to moon, solar flares, and radiation sickness, and walking on the moon (pp. 593-650); nature ofscience and scientists, especially as working in cooperation with society and politics. High school reading level. The exploration of the moon and some of the rocket development stories could be excerpted for junior high. Strong male and female characters. Some extramarital sex and love affairs.

Niven, Larry

Ringworld. High school. The implications of room-temperature superconductors is displayed along with genetic engineering and extremely large building projects. Ancient aliens had built a giant ring about their sun and then moved all of their life (as well as that of other worlds) there. High school.

Niven, Larry and Barnes, Steve

Dream Park. High school. This novel depicts a huge, life-size role-playing game, controlled by a computer. The reader is also acquainted with the South Pacific Cargo Cult culture.

Niven, Larry and Pournelle, Jerry

Lucifer's Hammer. High school due to length and reading level. Depicts the adjustments that must be made after a climatic change on earth. In this story a comet collides with the earth, but the cold and destruction of civilization is analogous to a post-atomic nuclear winter.

Mote in God's Eye, The. Advanced High School. Among the many other concepts in this novel are contact with alien life, alternatives to star travel, and the consequences of unbridled population expansion.

Piper, H. Beam.

Little Fuzzy. Adorable story for junior high and up. Sentient intelligence; communication with aliens; psychology; social-civil rights; scientific observation; scientific method.

Fuzzy Sapiens Sequel to *Little Fuzzy.* Scientific method; nutrition; biological adaptation. Junior high and up.

Pournelle, Jerry

Exiles to Glory. High school. A realistic depiction of advanced space suits, the real boredom of long range space travel, and an easy to digest discussion of orbital mechanics.

King David's Spaceship. Advanced high school. A depiction of Victorian-era technology space travel and an excellent comparison of battle tactics from different periods of history.

Rey, Lester Del

Moon of Mutiny. Young boy comes to maturity. Lots of technological situations involved in working in space and on the moon; indirect mention of applications of Newton's Three Laws; weightlessness (pp. 36-37); speaking in spacesuits p. 73); accidental tears in spacesuits (p. 80). High school.

Outpost of Jupiter. A youth comes to maturity. Momentum and impulse (Chapters 1 & 2), also uses of computers, calculus and applied physics in these first chapters; linguistics (p. 35); disease and quarantine (Ch. 6 onward); communication (pp. 124-129, Ch. 14, Ch. 16); working in spacesuits both in space and on moons. A young girl is a central character. High school.

Robinson, Spider and Jeanie

Stardance. Advanced high school. Consequences of low and zero gravity on the human body. A portrayal of the use of dance as a means of communicationwith an alien species.

Robinson, Spider

Telempath. Advanced high school. This apocalyptic novel shows the possible consequences of a tremendously increased sense of smell in humans. Advances the idea that there might be life on Earth that we don't know about because our senses don't normally detect it.

White, James

Hospital Station. Middle school. First book of an excellent series depicting the problems of communication and treatment in a space hospital that serves hundreds of wildly different forms of alien life. One of the interesting concepts shown is that of a method of classifying the different aliens according to body shape, locomotion, environment, and mental ability.

Appendix II

Part A

To Appendix I we add some more recently read books.

Asimov, Isaac.

Robots and Empire. This book splices together Asimov's robot stories with his famous Foundation trilogy. Many concepts are explored, including the clash of cultures and a the effects of a slowdown in scientific advance. This book is suitable for all age groups.

Where Do We Go From Here? A collection of short stories edited by Isaac Asimov. For each story, Dr. Asimov has provided questions concerning the use of science. Suitable for any reading audience.

Brin, David.

The Uplift War. This is part of a series by Brin exploring the idea that more advanced cultures should become responsible for improving less-advanced ones. This is the opposite of Star Trek's "Prime Directive" of non-interference. The human race i s responsible for uplifting dolphins and chimpanzees, for example. Confrontation between wholly alien cultures and the ingenious ways dolphins are modified to become tool-users are features of the story. Suitable for high school.

Card, Orson Scott.

Ender's Game. Young children are trained to become military leaders in an elaborate, and very violent, special school because mankind is facing an alien enemy and the current leaders are too old to learn the concepts necessary to defeat them. Very effective scenes involving weightlessness and inertia are depicted. Suitable for high school due to violence.

Speaker for the Dead. A continuation of Ender's story. The concepts found in this book deal with relativistic time dilation and DNA. The resolution of the alien conflict involves a knowledge and the workings of DNA. Suitable for high school audiences.

Cherryh, C. J.

Rimrunners. Placed in Cherryh's realistically conceived Union-Alliancefuture history, this novel is the story of a female soldier trying to make a new life for herself. The book contains excellent descriptions of shipboard life as well as an elaborate depiction of exoskeletal combat armor which can be compared to that described by Heinlein in Starship Troopers and Halderman in The Forever War. High school level.

Frankowski, Leo.

The Crosstime Engineer. First novel of a series dealing with the story of a man thrown back in time to medieval Poland, just prior to the Mongol invasion. Very realistic depictions of medieval life combined with very thorough descriptions of the introduction of more advanced technology and socialism. Suitable for high school audiences and up due to sex.

Gibson, William.

Neuromancer. Groundbreaking novel about a very possible near future. The story shows the consequences of a world-wide computer network and uncontrolled artificial intelligences. Also shown are bionic implants and human-machine interfaces. Suitable for high school due to violence and sexual situations.

McCaffrey, Anne.

Dragonsdawn. A recent novel in McCaffrey's series about the planet Pern. This book tells the story of the first settlers on Pern and how they genetically engineer native life into forms that can help them survive. The novel also includes information about vulcanism and human adaptation. Suitable for any audience.

Niven, Larry; Barnes, Steven; and Pournelle, Jerry.

The Legacy of Heorot. Heroic story of the attempt to colonize another world. The colonists try to settle on one small island in order to isolate the introduction of terrestrial domestic life. They encounter a deadly native lifeform and have to fight for survival. Included are elaborate depictions of a possible alien biology and life cycle. Suitable for high school readers due to violence.

Pournelle, Jerry.

Janissaries. The first book in a series about a group of mercenaries kidnapped from Earth and taken to an alien world to harvest a drug crop. The aliens have been doing this at regular intervals in man's past and the remnants of each group have survived with their particular culture. Features include the meeting of cultures from different time periods and the attempt to introduce modern technology and tactics. Suitable for junior high and high school readers.

Black Holes. A collection of short stories, edited by Dr. Pournelle, dealing with the subject of black holes. Each story is directly concerned with the science and theory of gravitation as well as astronomy and spaceflight. Suitable for junior and high school audiences.

Preuss, Paul.

Arthur C. Clarke's Venus Prime. This is a series of novels (four so far) that each use one of Clarke's short stories as the foundation for the continuing story of Sparta, a biotechnically enhanced secret agent. The books contain very realistic depictions of spaceflight, bionics, and the hazards of exploring extremely hostile environments such as Venus and Jupiter. Each book also includes computer drawn designs of the technology that appears in the text. Suitable for high school readers.

Smith, E. E. "Doc".

Galactic Patrol. Representative of a series of exciting novels written in the '40s and '50s about a future police force fighting ultimate evil. Especially effective are the depictions of an inertialess drive and the consequences of the removal of inertia. This book can also be used to show "fake science" with its ignorance of special relativity. Suitable for all readers.

Tuning, William.

Tornado Alley. A story of the near future in which man confronts nature in the form of tornadoes. Extremely realistic depictions of the formation and actions of tornadoes are given along with possible methods for controlling them. Good information on meteorology in general is also provided. Suitable for all audiences.

Part B

The following list of references specifies science concepts presented in works of science fiction. The journal articles present works suggested for use in science classes.

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Marks, G. (1978). Teaching biology with science fiction. *The American Biology Teacher, 40,* 275-279.

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